Coronagraphic Phase Retrieval

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Abstract

We discuss and show results of simulated high spatial frequency *phase retrieval* through a Lyot type type *coronagraph* with a 7 segment primary mirror. We desire to accurately determine the wavefront spatial frequency components responsible for focal plane "speckle" and, ideally, remove them, effectively creating a dark hole in the focal plane for direct planetary detection.

Viewgraphs at http://jansky.gsfc.nasa.gov/OSCAR
Report at http://ngst.gsfc.nasa.gov/science/isimpage.html

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Coronagraphic Precision Wavefront Sensing

- **High Contrast Origins Science Strategies (HCOSS)**
  ***Coronagraph* proposed as a science instrument for NGST.**
  J.Trauger (JPL), R.Lyon(GSFC) et.al.
- **NGST => segmented actuated PM, 6 DOF SM and active optical bench <=> WFE~10 cycles/aperture, < $\lambda/14$ diffraction limited**
- **Coronagraph =>speckle limited due to coherent scatter from residual WFE.**
- **Studied high spatial freq wavefront sensing, via phase retrieval, "tweeter" DM to remove speckle.**
  - phase retrieval "sees" entire optical path to focal plane of coronagraph.
  - little additional hardware required.
- **Simulate phase retrieval through coronagraph**
  - coronagraph removes diffraction core in PSF.
  - Apodized PSFs => greater SNR for in PSF wings.
  - *hypothesize*
    - **higher accuracy for high spatial freq. phase retrieval**
    - **lower accuracy for low spatial frequency phase retrieval**
- **Demostrated *proof of principle***

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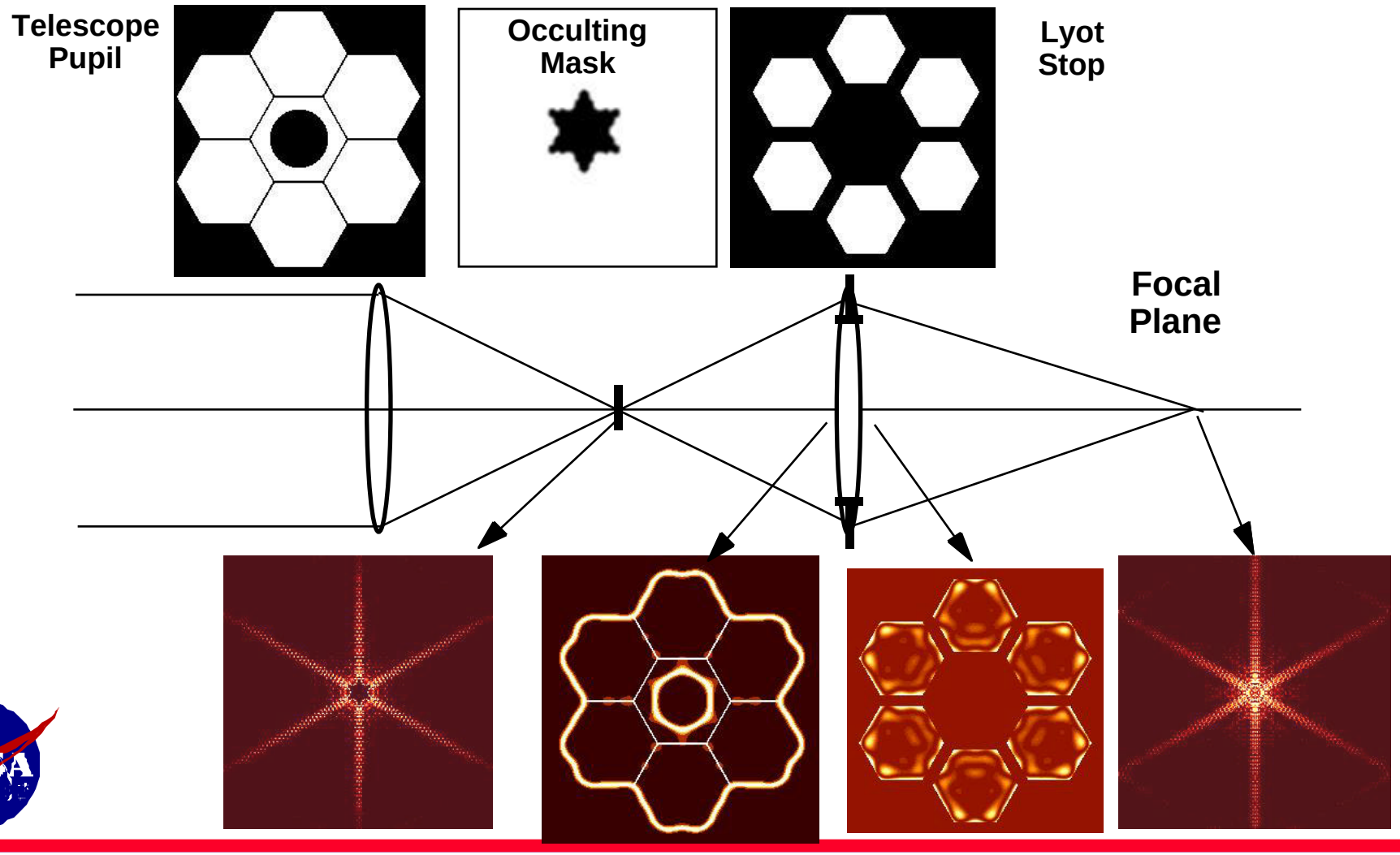
Principle of Lyot Coronagraph



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PSF+

PSF-

Poly-Pis/Tilt Algorithm

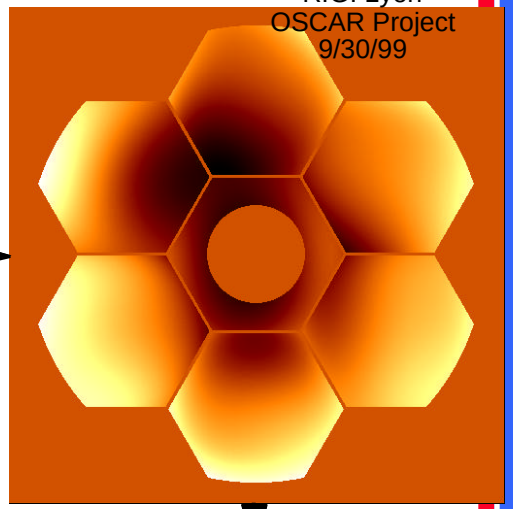
Misell Algorithm

Phase Div.
- focus
- field
- lambda

Quasi-Linear Algorithm

"Trending" FeedForward Kalman Filter

Phase Unwrap
Directed Acyclic Graph

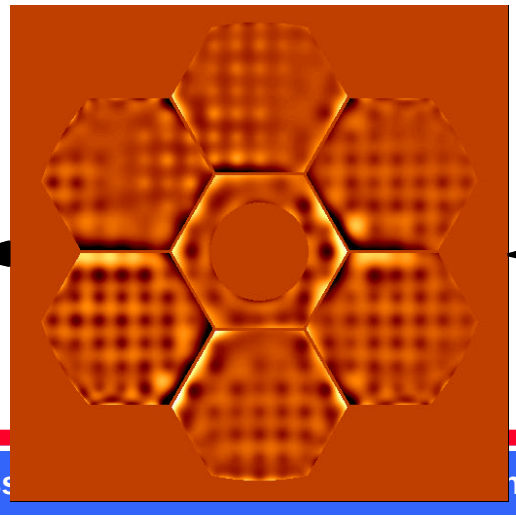


Eigenvector Fit
calibration loops
SVD - Algorithm

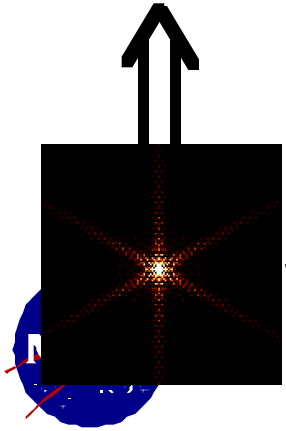
Metrics
Min rms WFE
Enc. Energy
PSD Law

Control Law
Choice of Metric drives Control Law

DM Correct



New PSFs



Optical Control Loop

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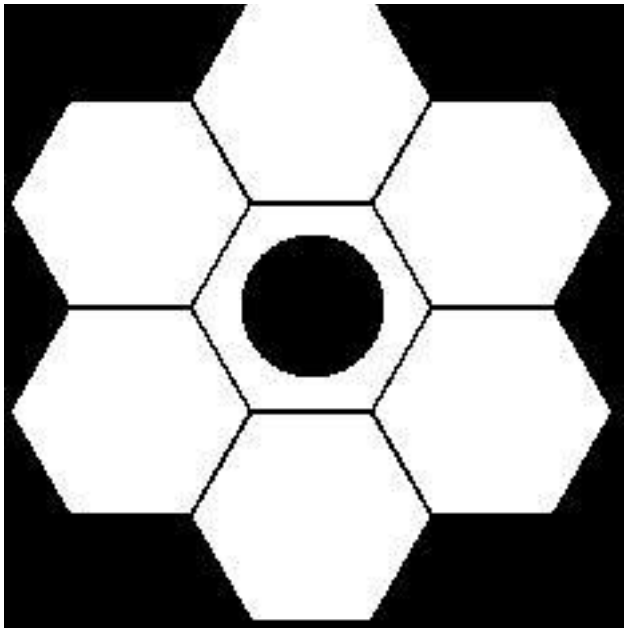

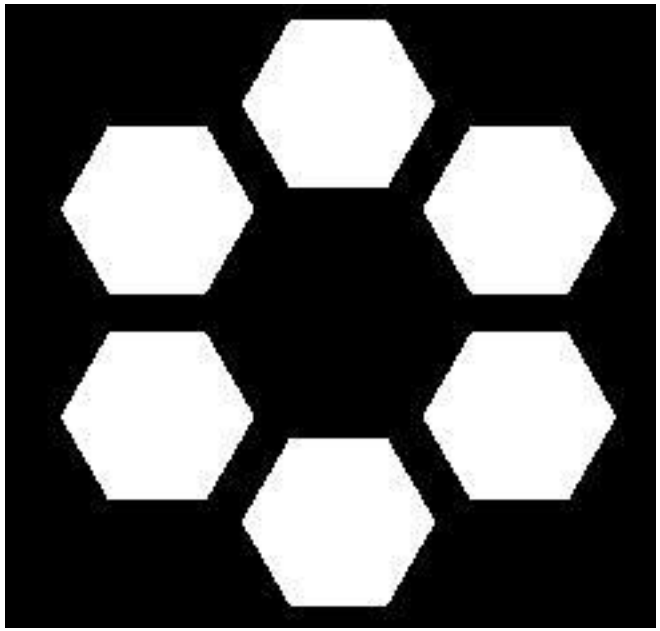

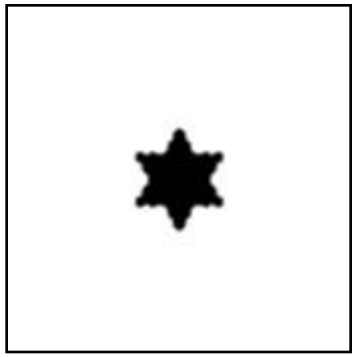

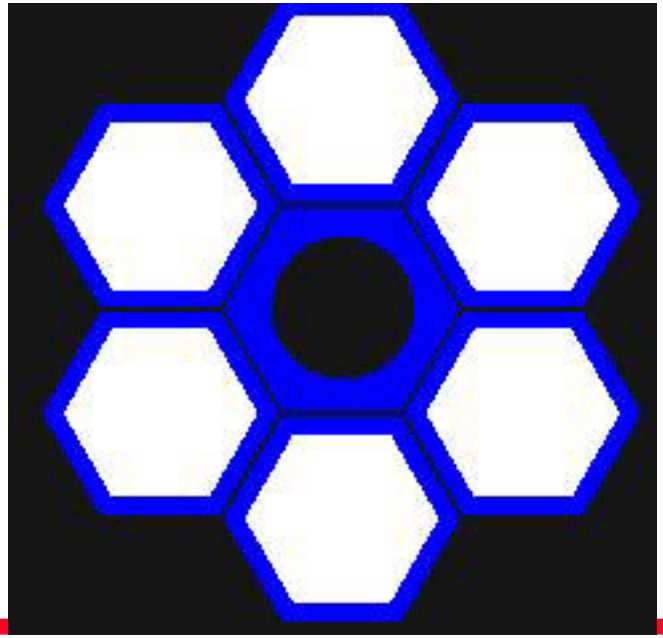

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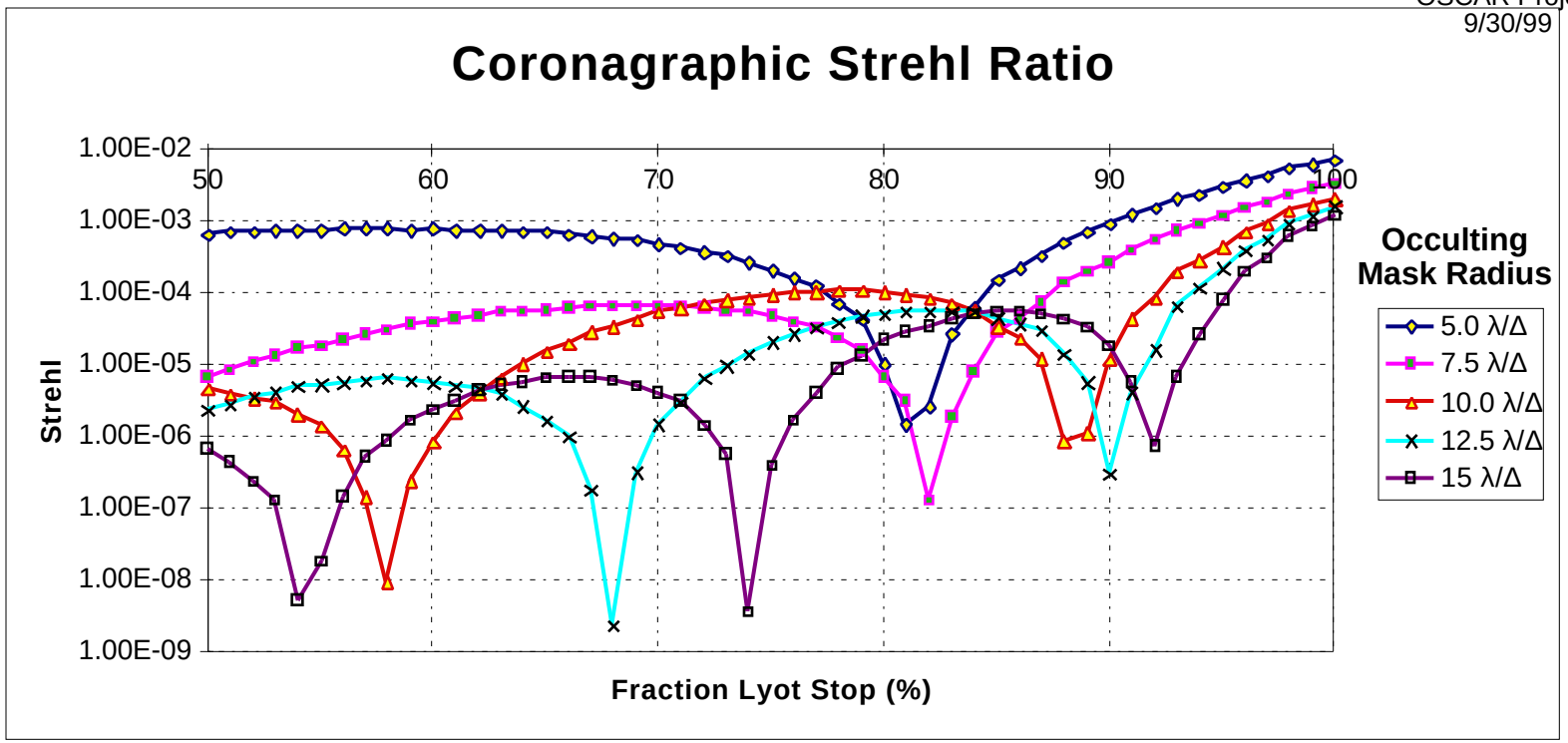

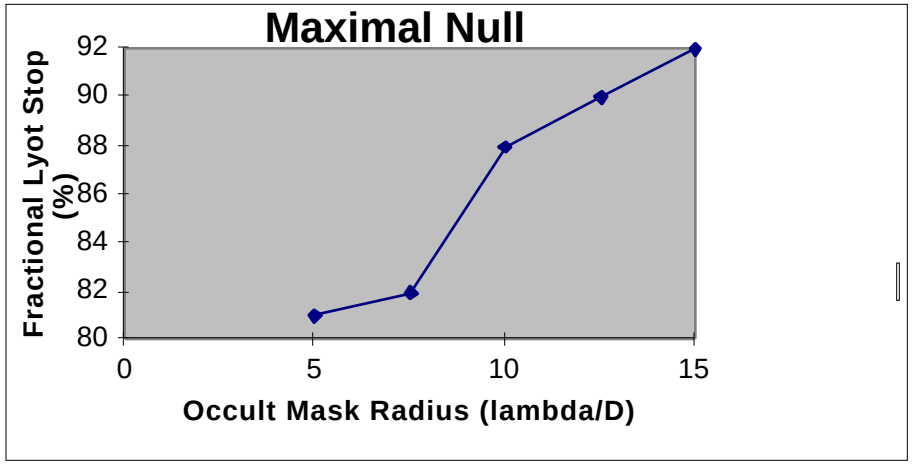

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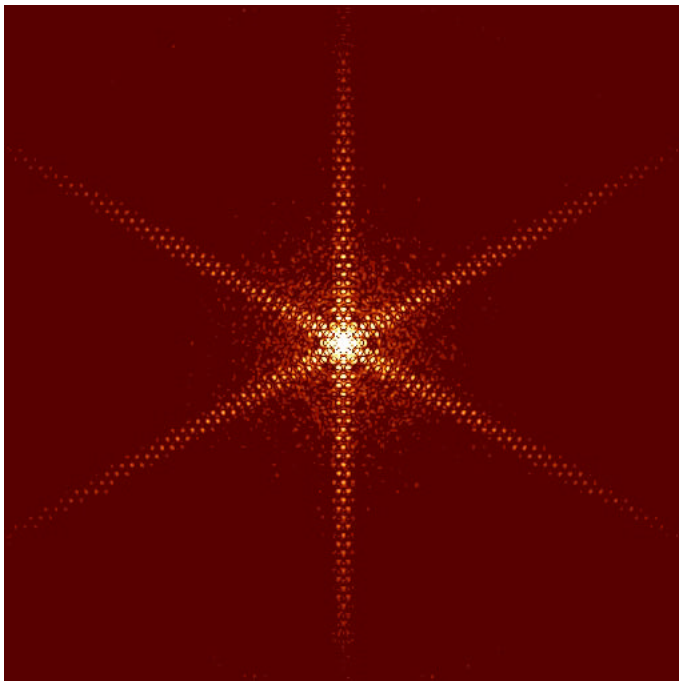
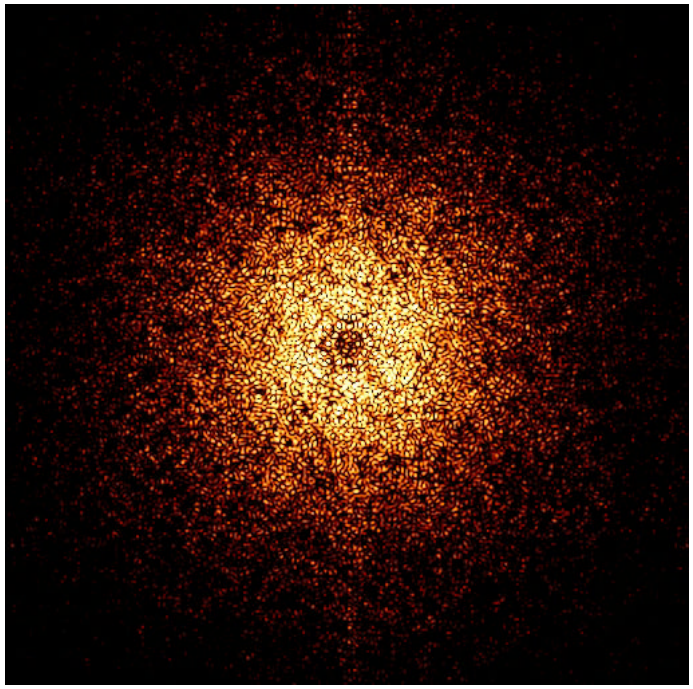
Raw PSF
without Coronagraph



Coronagraphic PSF
Before Phase Retrieval
Speckle Removal



images are not on same color scale
and do not have same logarithmic stretch

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Misell Type Phase Retrieval Simulation

- 20 x 20 grid of mid-range DM => 10 cycles/aperture correction
- Occulting mask with ave radius of 10 rings (10 λ/D).
- Nulls at 57% and 88% Lyot stop, 88% Null for max photons
- 12 bit detector, 5 ADU gaussian noise, quantization, no jitter
- 4 psfs {-2,-1,+1,+2} λ of focus, scaled to max dynamic range.
- Used 4 psf Misell type algorithm w/zero phase as start pt.
- Rapid convergence, only few cases run to date.
- Will run large Monte-Carlo simulation.

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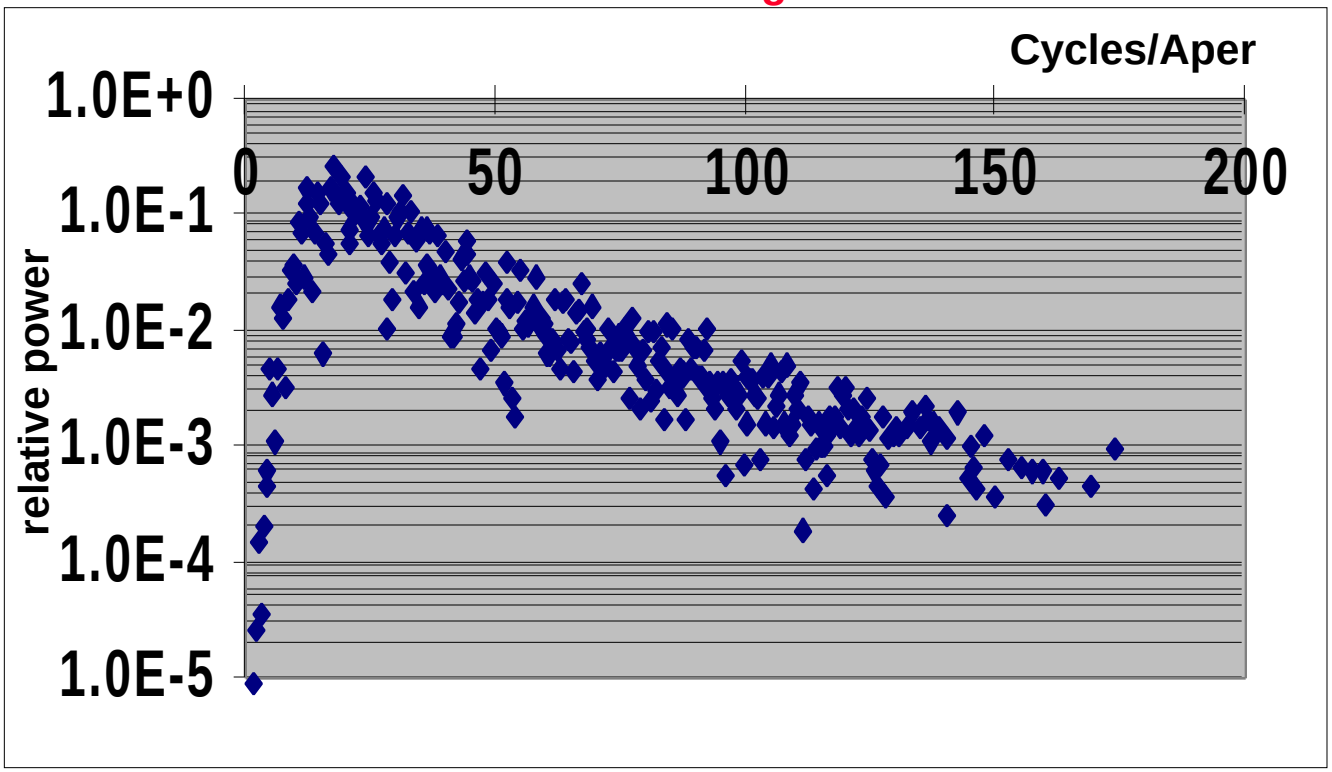
PSD of Mid-range DM Phase Correction

- **Total WFE: σ_T ~ $\lambda/14$ after Mid range DM,**
- **PSD(f) ~ $1/f^2$**
- **for f > 10 cycles/aperture, σ(WFE) = λ/40 (HST) .**
- **In simulation assumed roll up to 10 cyc/aper.**

Wavefront PSD after mid-range DM correction



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4 PSF Misell Type Phase Retrieval Algorithm

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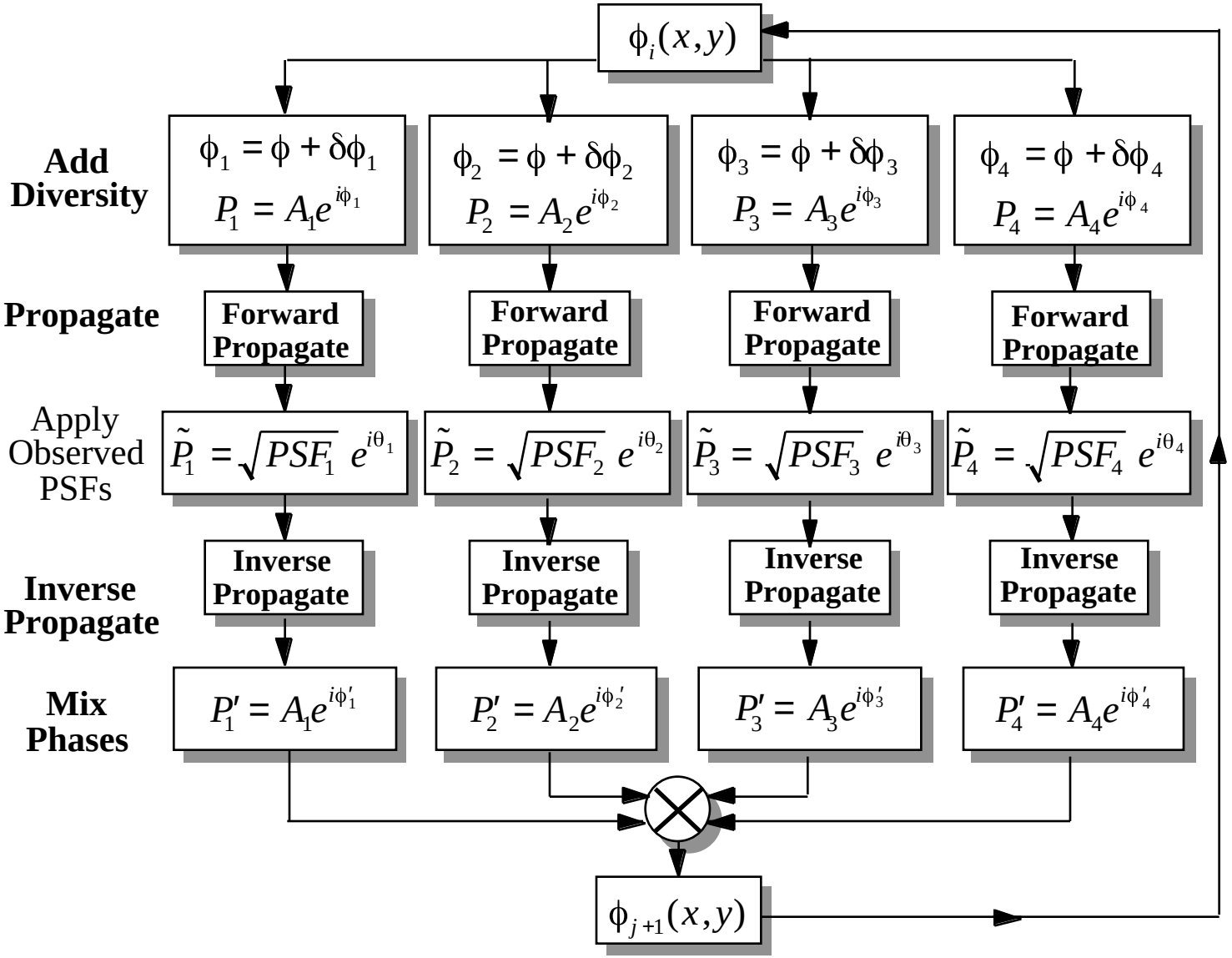

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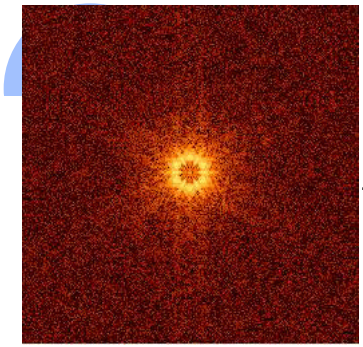
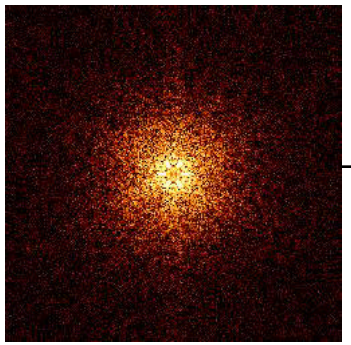
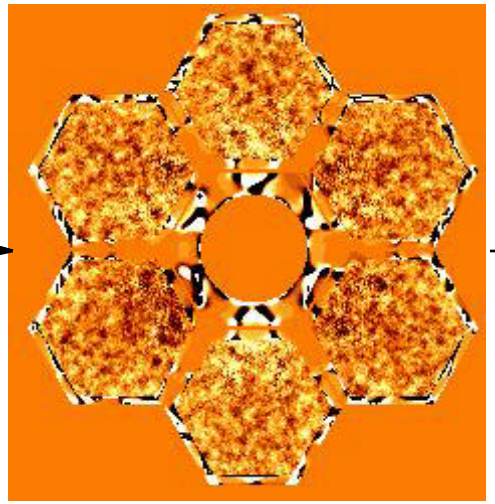
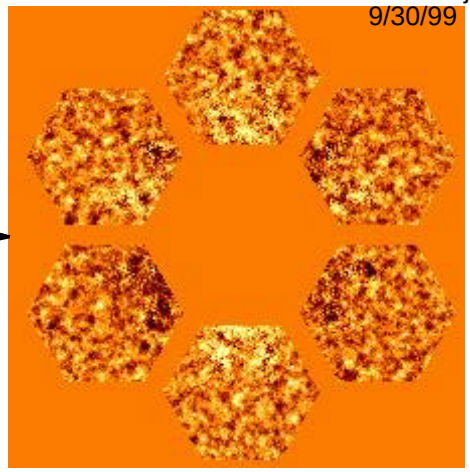




Misell

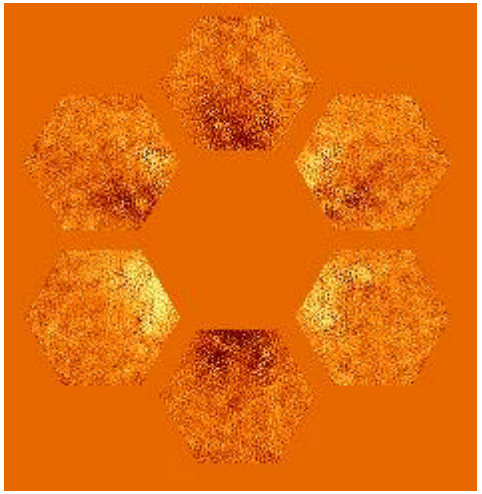


Solution
$\sigma \sim \lambda/32$



Edge Masked
$\sigma \sim \lambda/30$

- **low freq. residual**
  - **caused by occulted PSF**
    => unconstrained lo freq.
- **very hi-freq residual**
  - **uncorrelated noise in 4 PSFs**



Difference
$\sigma \sim \lambda/45$

“True” Phase
$\sigma \sim \lambda/40$

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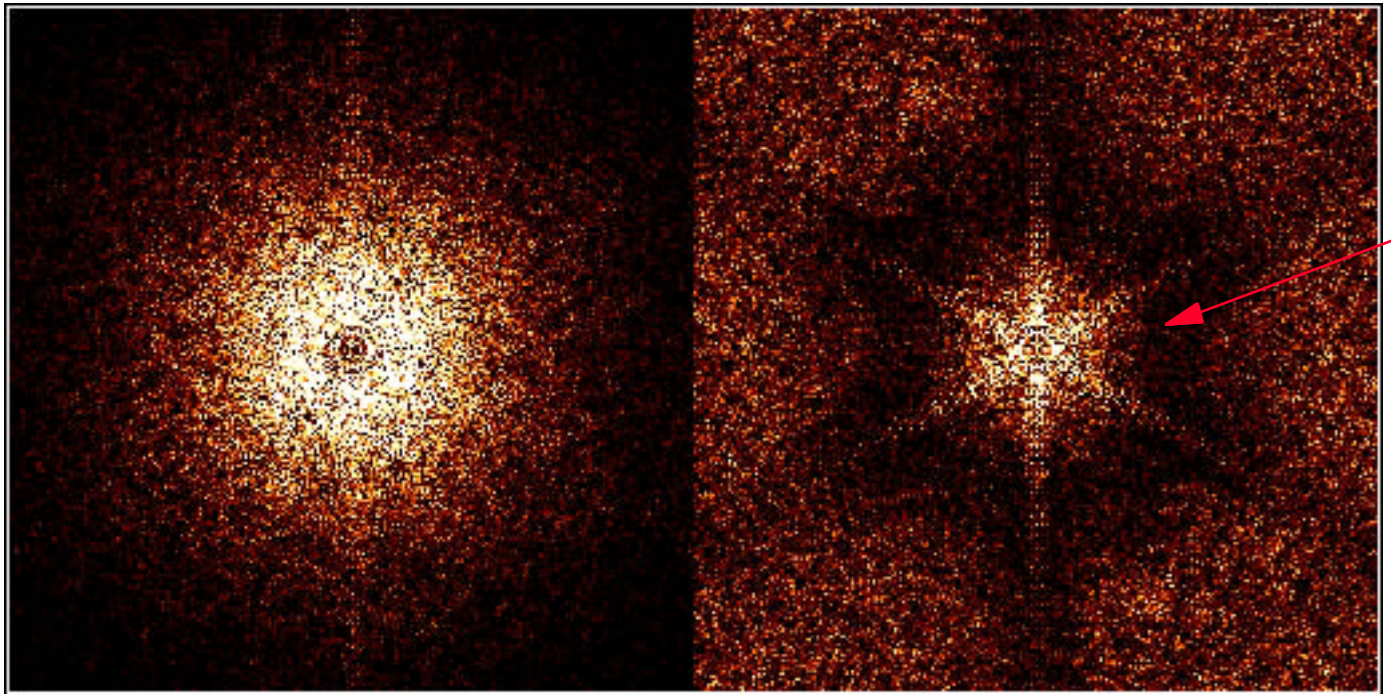
Coronagraphic PSF
Before **Phase Retrieval**
Speckle Removal

Coronagraphic PSF
After **Phase Retrieval**
Speckle Removal



Dark Hole

NASA

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and have same logarithmic stretch

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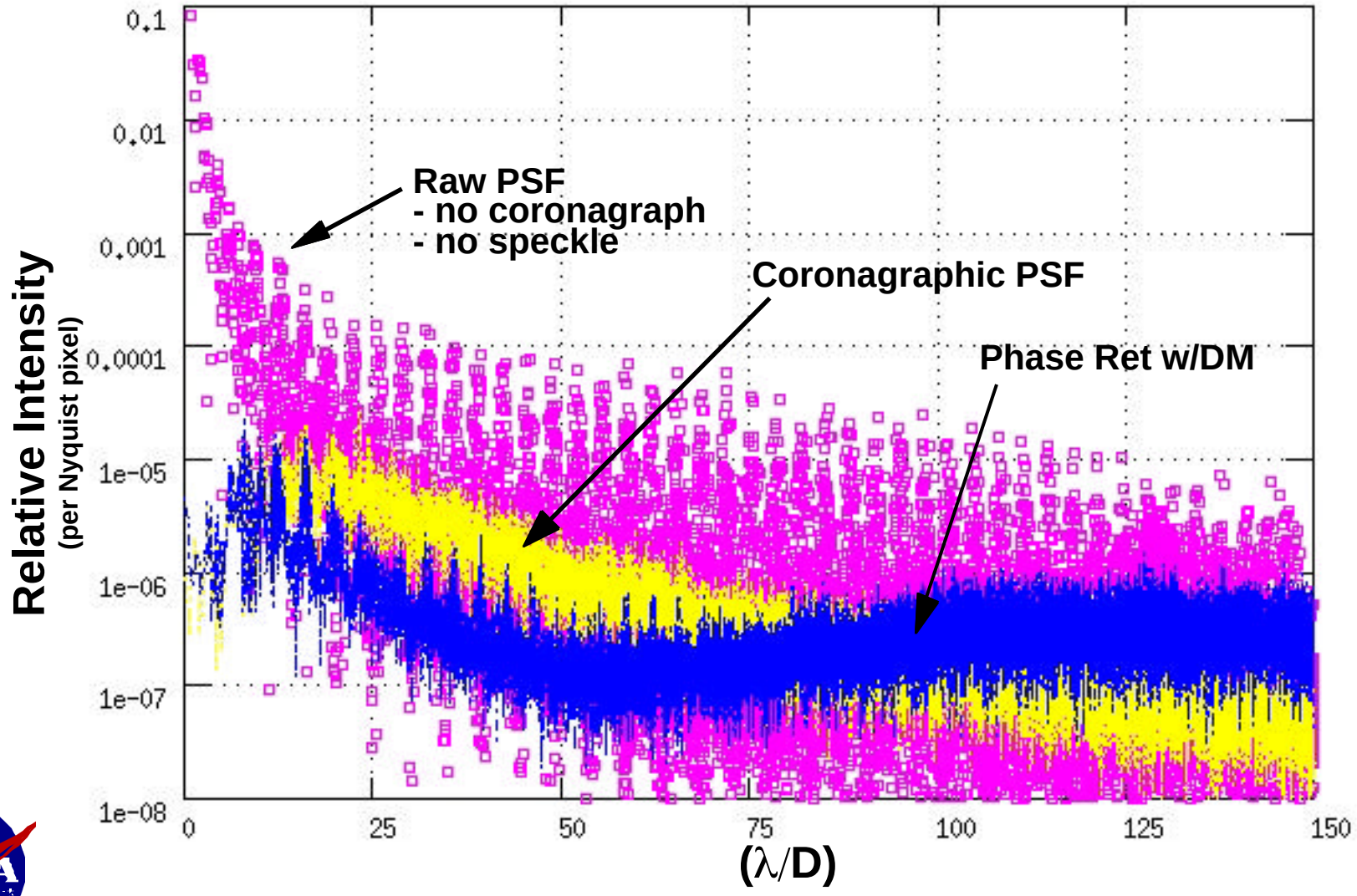

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Results and Future Plans

- **Results**
  - Coronagraphic Phase Retrieval possible with segmented mirrors.
  - Low freq PR induced errors should be removed before “tweeter” DM.
  - Accuracy/Precision not yet known.
  - Effects of jitter not yet known.
  - Effects of fit to “tweeter” not yet known.
- **Plans**
  - Run large scale Monte-Carlo simulation to assess accuracy/precision
  - Include:
    - **ranges of low, mid and hi-spatial frequencies.**
    - **telescope LOS jitter.**
    - **noise, quantization, sampling, pixelization**
    - **residuals due to mid- and hi-range DMs**
    - **etc...**